# EXPERIMENT E951 POWER SUPPLY TO PULSE A 14.5 TESLA SOLENOID MAGNET

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DATE: 02/09/02

## Introduction:

The project goal is to pulse a magnet with 20 cm diameter bore, capable of a peak field near 15 T and a repetition rate of about 30 minutes.

Funding realities make it prudent to consider a stageable design with the following 3 cases:

1. The magnet achieves peak field of 5 T @ 84 K.
2. The magnet achieves peak field of 10 T @ 74 K.
3. The magnet achieves peak field of 14.5 T @ 30 K.

**Parameters of Pulse Magnet System with 1 sec flat top**

| | Units | **Case 1** | **Case 2** | **Case 3** |
|---|---|---|---|---|
| Outer radius | (cm) | 30.0 | 30.0 | 40.0 |
| Copper mass | (kg) | 1943 | 1943 | 3644 |
| Voltage | (V) | 150 | 300 | 300 |
| Peak current | (A) | 3600 | 7200 | 7200 |
| Field | (T) | 5.0 | 10.0 | 14.5 |
| Inductance | (mH) | 138 | 138 | 436 |
| Initial temperature | (K) | 84 | 74 | 30 |
| Time t1, to end of flat tap | (s) | 8.2 | 7.3 | 16.3 |
| Pulse length, tp | (s) | 11.1 | 10.1 | 24.1 |
| Initial Resistance | (mOhms) | 30.2 | 23.5 | 11.0 |
| Resistance at t1, | (mOhms) | 34.1 | 35.3 | 33.0 |
| Resistance at tp, | (mOhms) | 34.1 | 37.2 | 38.2 |
| Dissipation at tp, | (MJ) | 2.70 | 9.1 | 15.2 |

Cases 2 and 3 require the same power supply, but differ in the magnet cooling scheme.

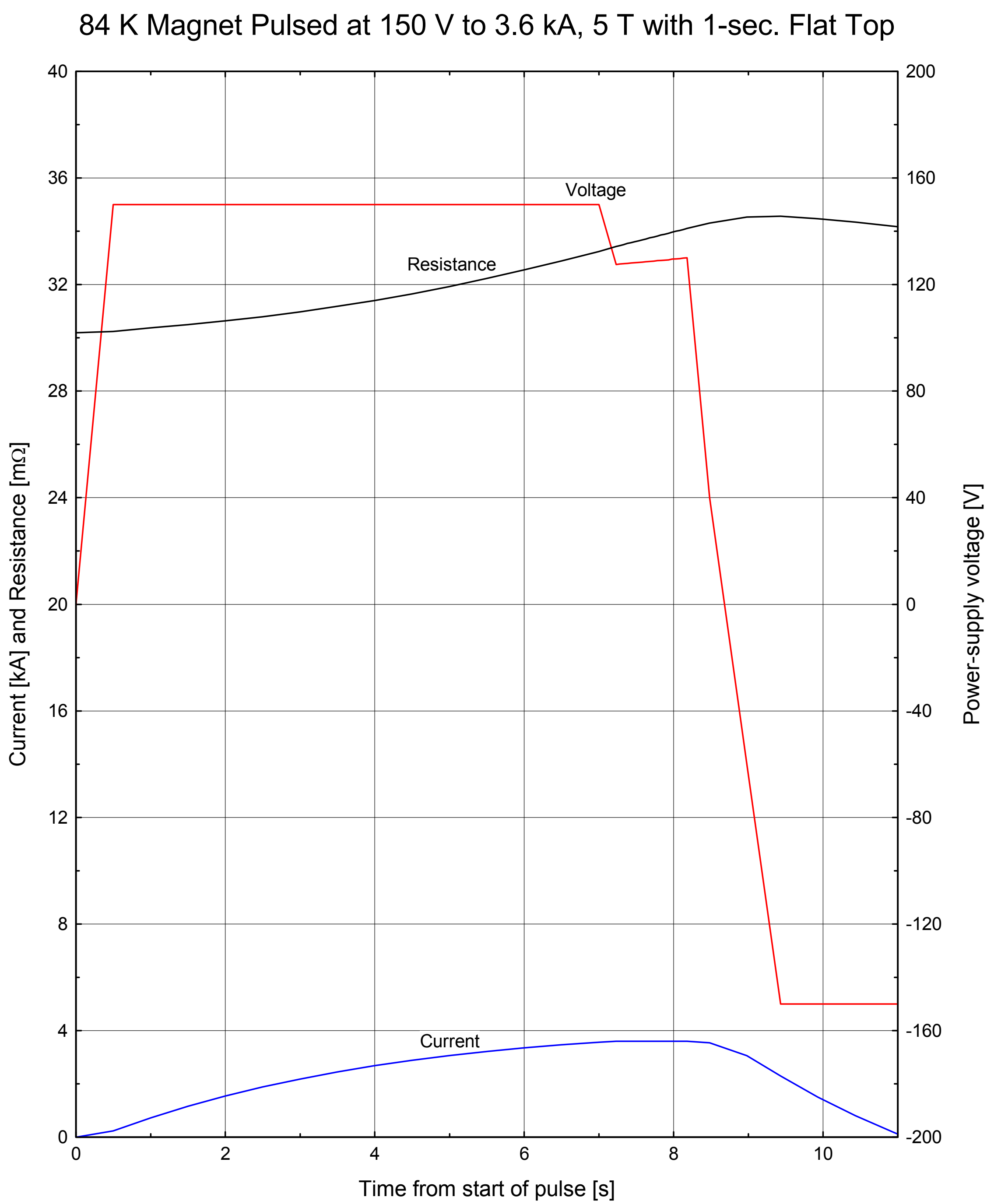



Fig.1. Performance of the 5T magnet with the Case 1 power supply.

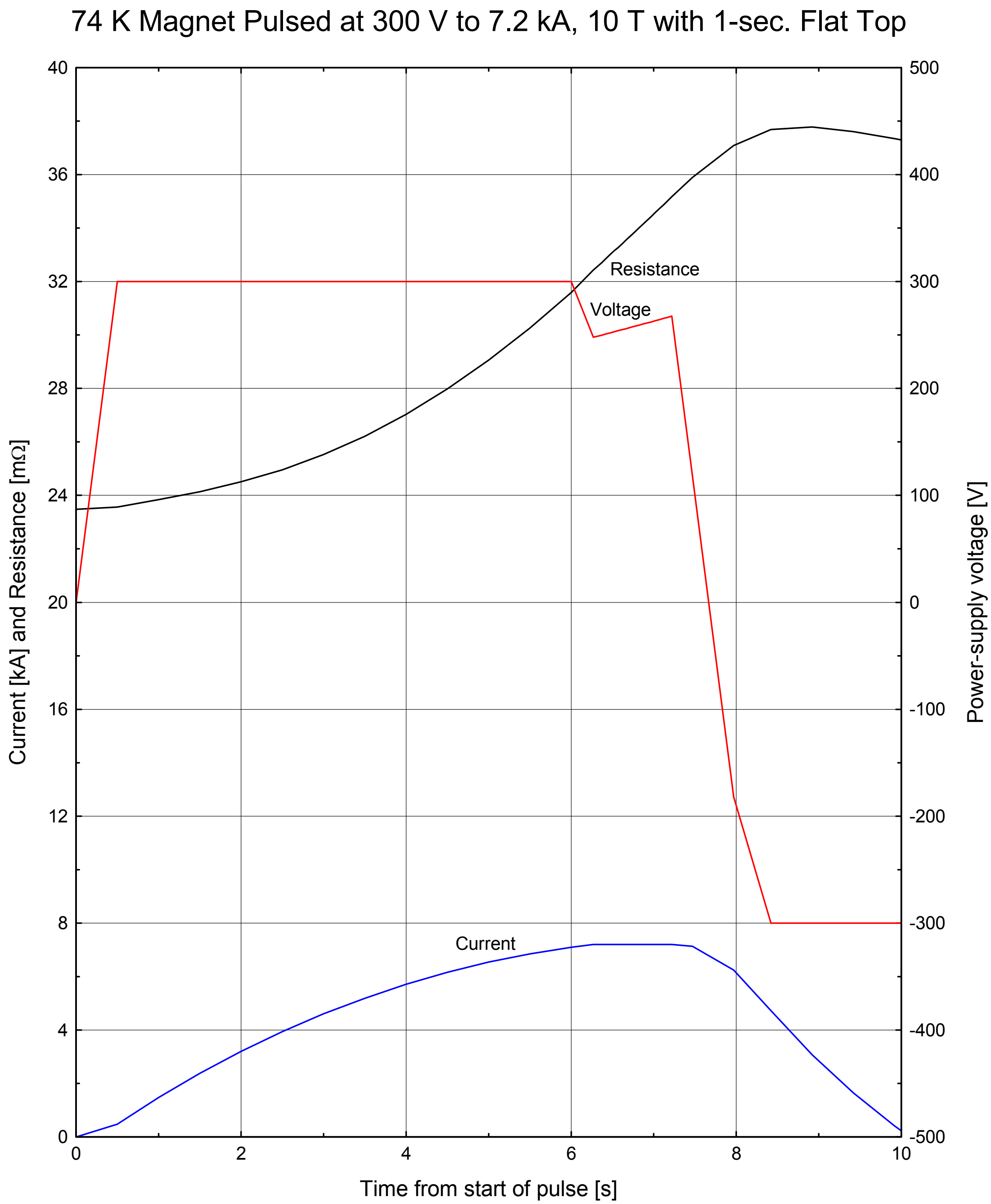



Fig.2. Performance of the 10T magnet with the Case 2 power supply.

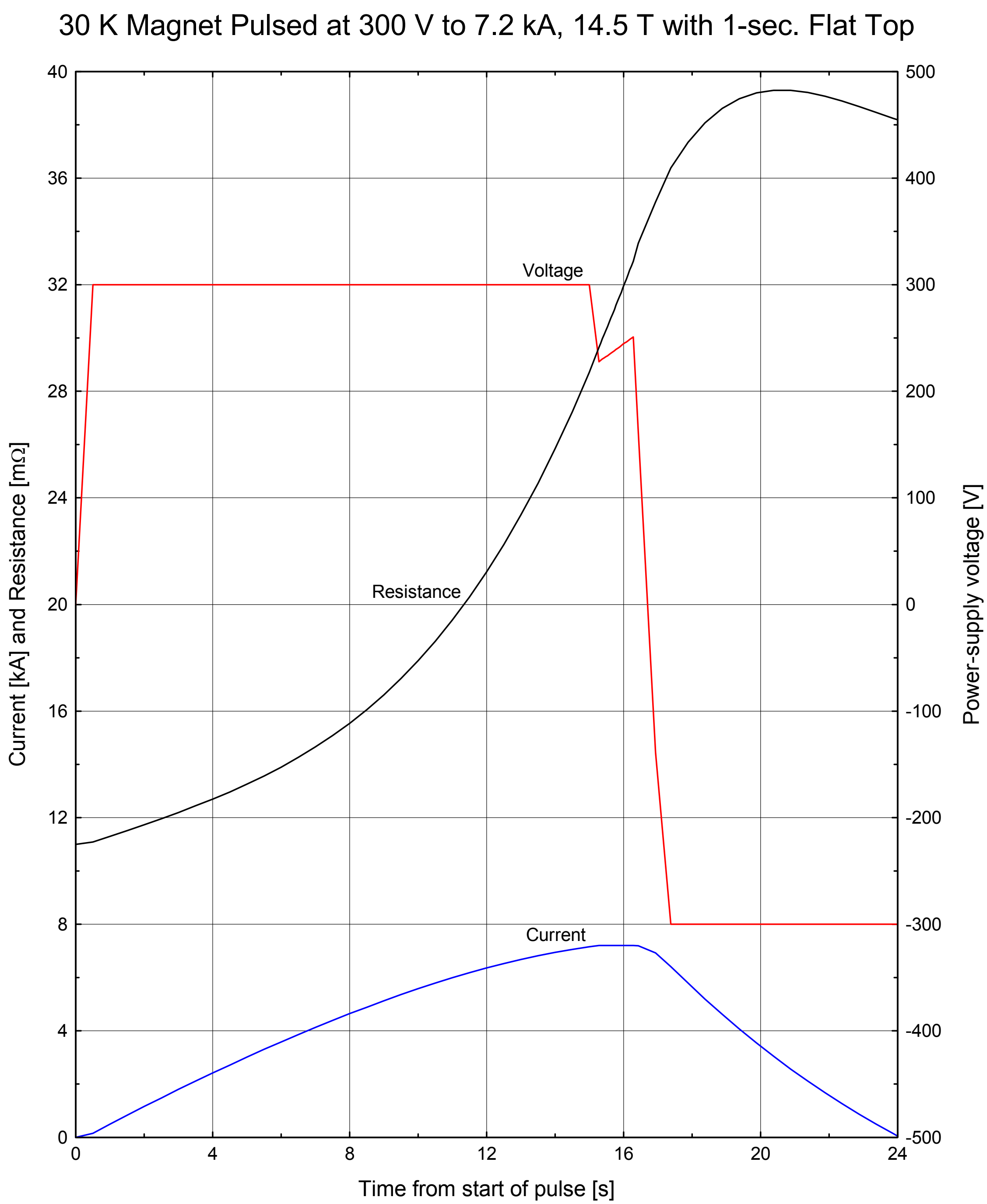



Fig.3. Performance of the 14.5T magnet with the Case 3 power supply.

From the power supply point of view, we will start with a

**540 KVA power supply rated at 3600 A, +/-150 V (Case 1)**

to support case 1, and for cases 2 and 3 we will have

**four 540KVA in series/parallel to generate 7200A, +/300 V (Cases 2-3).**

The 540KVA power supplies are thyristor-control six-pulse rectifiers, available at Brookhaven Labs from previous experiments.

These power supplies are presently configured as DC power supplies.

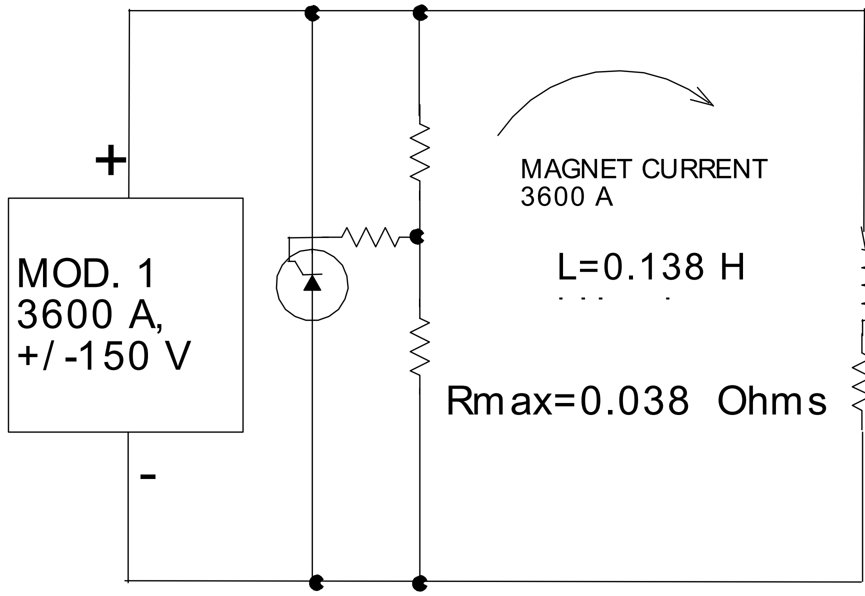
We need to modify their regulators to be able to pulse them.

The controls and interlocks of these power supplies must be updated.

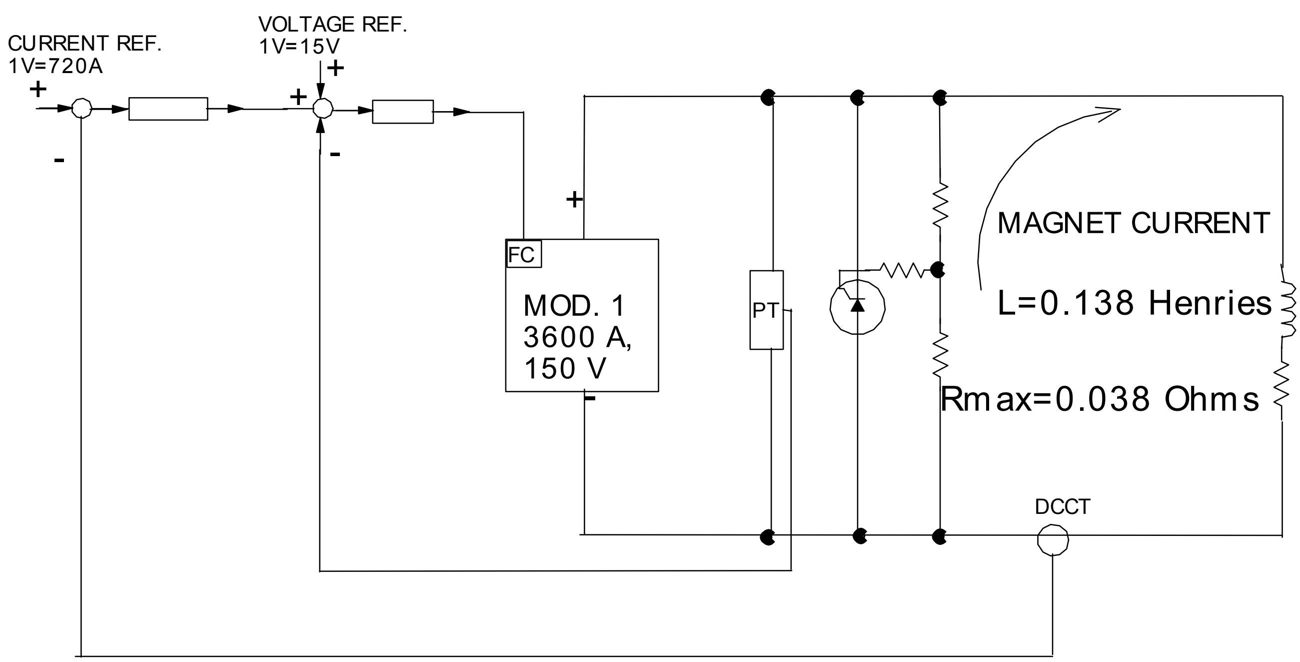
Similar upgrades have been made during the Booster project with great success.

**Case 1 power supply (5 T magnet):**

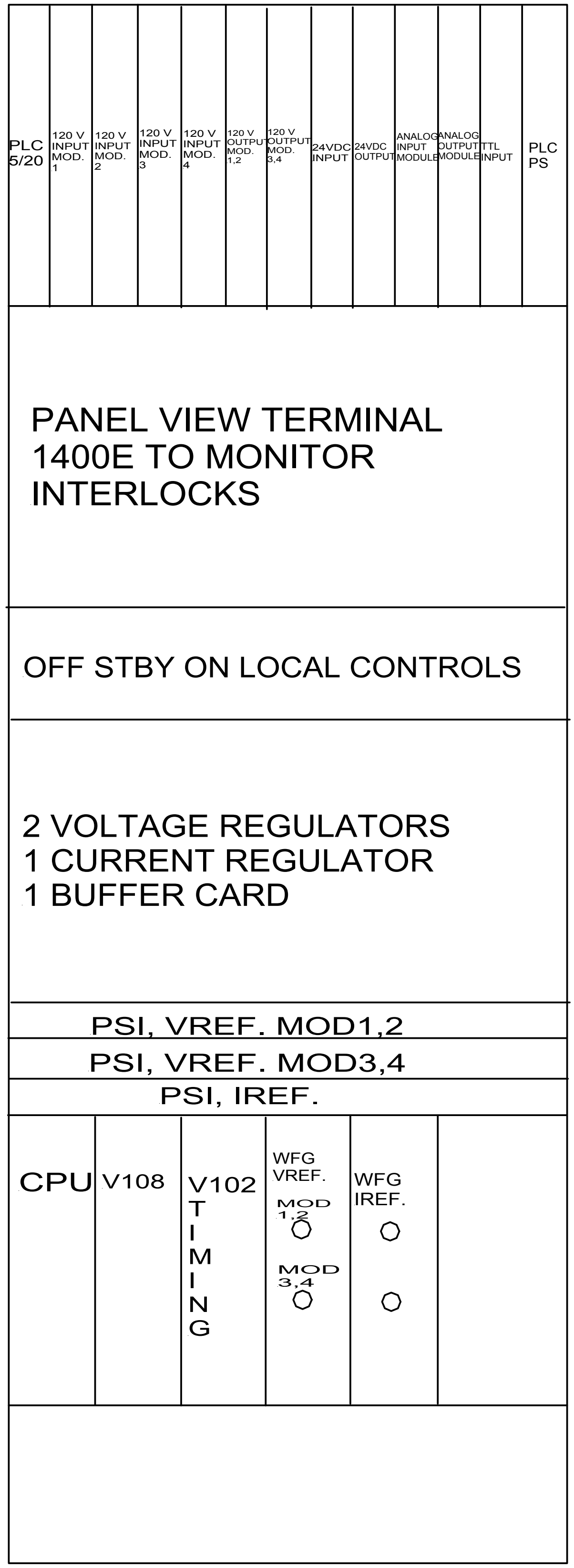
MUON EXPERIMENT POWER SUPPLY
FOR PULSING A 5 TESLA MAGNET
3600 A, +/- 150 V .




5 T MAGNET MUON EXPERIMENT POWER
SUPPLY REGULATION CONTROLS



MUON EXPERIMENT POWER SUPPLY
CONTROLS RACK



**Case 1 power supply (5 T magnet):**

This power supply will be a thyristor phase control power supply rated at **3600A, +/-150 V.**

This power supply exists at Brookhaven from previous experiments.

The 3-phase, 480-V input power will be fed from an existing disconnect switch.

The power supply will have an AC circuit breaker.

A new regulator will be implemented based on the existing design for the AGS Main magnet power supply.

The power supply will be fully programmable from 0 to 3600 A.

It will have a voltage regulator as the inner loop and a current regulator as the outer loop.

Both voltage reference and the current reference will be generated from a high-level computer algorithm for a given magnetic field pulse and a given function of the load resistance as a function of current and time.

We need to replace the voltage feedback sensor with a LEM DCPT (DC potential transformer).

We need to replace the existing current sensor (shunt) with a LEM DCCT (DC current transformer).

These sensors have been successfully used in the past in various power supply systems.

All the old interlocks will be updated using an Allen Bradley Programmable Logic Controller (PLC).

This PLC will be programmed to make decisions on the interlocks and safely turn of the power supply if an interlock occurs.

The power supply will have the following interlocks:
1. DC Over-current
2. RMS magnet current interlock
3. AC Over current
4. Blower failure
5. Ground Fault
6. Magnet faults
7. Magnet resistance interlock.
8. Cryo-interlocks

In case of any interlock failure, the power supply will be phased to 150 degrees in 100 msec.

This means the power supply voltage will be –150 volts, the current then will go to 0 amps in 3 sec maximum time, depending where the interlock occurs in the cycle.

Then the AC circuit breaker will be commanded to open by the PLC regardless whether the magnet current is at 0 Amps or not.

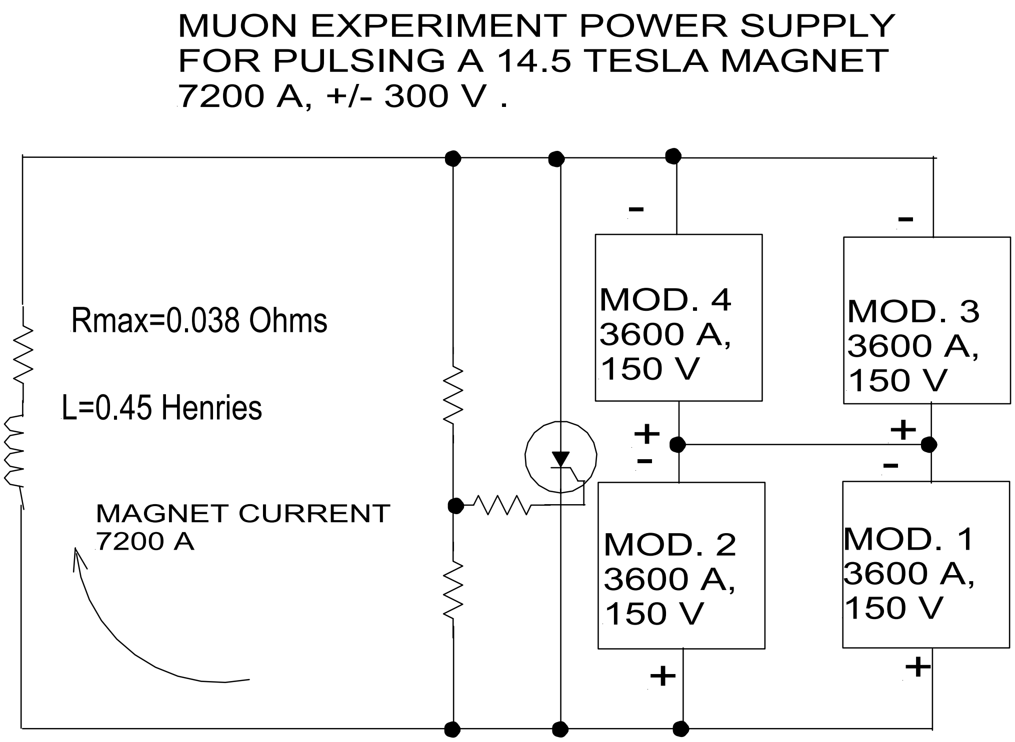
A crowbar circuit based on self-triggering silicon control rectifiers (SCR's) will be implemented to short the magnet if the magnet voltage becomes greater than 350 V.

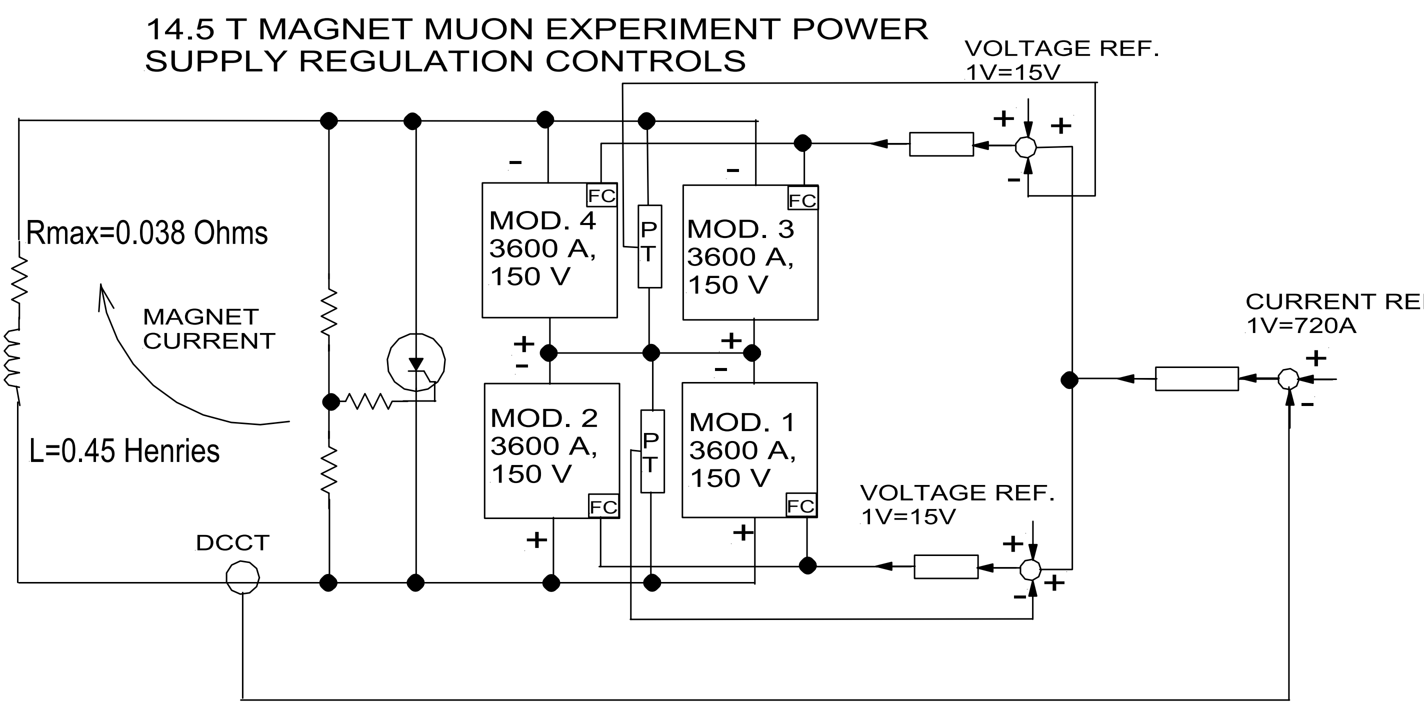
In this case, the magnet current will decay to 0 amps with the L/R magnet time constant which is typically **3.6 sec.**

**Note: $L = 138$ mH, $R_{max} = 38$ mΩ.**

**Minimum repetition rate is 5 minutes**

**Case 2-3 power supply (10, 14.5 T magnet):**



**<u>Case 2-3 power supply (10, 14.5 T magnet):</u>**

This power supply will be a thyristor phase control power supply composed of 4 series/parallel Case-1 power supplies. It will be rated at **7200A, +/-300 V**.

These power supplies exists at Brookhaven from previous experiments and will be modified as described in Case 1.

The 3-phase, 480-V input power will be fed from existing disconnect switches.

The power supply will have four AC circuit breakers, one per power supply.

Two parallel power supplies (MOD 1 and MOD 2) will be fed from the same existing substation and the other two (MOD 3 and MOD 4) from a different existing substation. This will not require any modifications to our existing substations regarding power supply input power requirements.

The power supply will be fully programmable from 0 to 7200 A.

It will have two voltage regulators as the inner loops and a current regulator as the outer loop.

**Note: For Case 2, $L = 0.138$ H, $R_{max} = 38$ mΩ, for Case 3, $L = 0.436$ H, $R_{max} = 37$ mΩ.**

In order to share current properly between parallel power supplies, we intend to run 2-in water-cooled busses from the + terminal of MOD 2 to the magnet and from the + terminal of MOD 1 to the magnet. The same is true for the - terminal of MOD 4 and MOD 3.

**The anticipated overall bus resistance should not exceed 2 mΩ.**

A crowbar circuit based on self-triggering silicon control rectifiers (SCR's) will be implemented to short the magnet if the magnet voltage becomes greater than 350 V.

In this case, the magnet current will decay to 0 amps with the L/R magnet time constant which is typically **3.6 sec for Case 2 magnet, 12 sec for Case 3 magnet.**

All the old interlocks will be the same as Case 1 power supply and will be updated using an Allen Bradley Programmable Logic Controller (PLC).

**Minimum repetition rate for case 2 magnet is 20 minutes, for case 3 magnet 30 minutes**

**Schedule:**

| | | | |
|---|---|---|---|
| | MUON POWER SUPPLY SCHEDULE | | |
| | DATE 1/29/02 | | |
| Yearly quarters | *1 Design & Development* | *2 Fabrication* | *3 Installation/commissioning* |
| 1 | Design for case 1 ps | Procurement | |
| 2 | | Fabrication of case 1 ps | |
| 3 | | | Installation of case 1 ps |
| 4 | | | Commissioning of case 1 ps |
| 5 | Design for case 2,3 ps | | |
| 6 | | Fabrication of case 2,3 ps | |
| 7 | | | Installation of case 2,3 ps |
| 8 | | | Commissioning of case 2,3 ps |
| | | | |

**The Case 1 power supply should be compete by the end of the $4^{rd}$ quarter, middle of FY03.**

**The Case 2-3 power supply should be complete by the end of the $8^{th}$ quarter, middle of FY04.**

This schedule is spread apart over 2.7 years, taking into account other projects of the C-AD Power Supply Group.

All the parts purchased should be bought at the same time for the following reasons:

1. We need almost all the parts for the controls rack for Case-1 power supply.
2. The DC bus should be bought at the same time to save money.

## Cost estimate:

The following table includes burden of 87% on labor and burden of 47% on materials.

| **Muon Power Supplies** | | | | **Duration (man days)** | | | |
|---|---|---|---|---|---|---|---|
| **Description** | **$ Labor** | **$ DTS** | **$ Purch** | **Engr** | **Dsgn** | **Tech** | **$ DTS** |
| ***MUON PS- 1 Design & Development*** | **33469** | | | | | | |
| **Case1 PS 3600A, +/-150V** | 19461 | 0 | 0 | 13 | 8 | 4 | 0 |
| **Case 2,3 PS 7200A, +/-300V** | 14008 | 0 | 0 | 8 | 8 | 3 | 0 |
| | | | | | | | |
| ***Muon PS - 2 Fabrication*** | **82353** | | **145383** | | | | |
| **Case1 PS 3600A, +/-150V** | 45369 | | 145383 | 31 | 0 | 25 | 0 |
| **Case2,3 PS 7200A, +/-300V** | 36983 | | 0 | 15 | 0 | 32.5 | 0 |
| | | | | | | | |
| ***Muon PS- 3 Installation*** | **84116** | **4034** | | | | | |
| **Case1 PS 3600A, +/-150V** | 29557 | 1009 | 0 | 10 | 0 | 29 | 2 |
| **Case 2,3 PS 7200A, +/-300V** | 54558 | 3026 | 0 | 15 | 0 | 57 | 5 |
| | | | | | | | |
| AMOUNT FOR CASE1 IN $ | 94388 | 1009 | 145383 | | | | |
| **TOTAL CASE1 $** | **240780** | | | | | | |
| **TOTAL WITH 20% CONTINGENCY $** | **288936** | | | | | | |
| | | | | | | | |
| AMOUNT FOR CASES 2,3 IN $ | 105550 | 3026 | 0 | | | | |
| **TOTAL CASES 2,3 $** | **108575** | | | | | | |
| **TOTAL WITH 20% CONTINGENCY $** | **130290** | | | | | | |
| | | | | | | | |
| TOTAL AMOUNT IN $$$ | 199938 | 4034 | 145383 | | | | |
| **TOTAL NO CONTINGENCY $** | **349355** | | | | | | |
| **TOTAL WITH 20% CONTINGENCY $** | **419226** | | | | | | |